Correcting the Corneal Power Measurements for Intraocular Lens Power Calculations After Myopic Laser In Situ Keratomileusis

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• PURPOSE: To describe and evaluate a refraction-derived method and a clinically derived method to calculate the correct corneal power for intraocular lens (IOL) power calculations after laser in situ keratomileusis (LASIK) and to compare the results to the commonly used history-derived method.

• DESIGN: Interventional case series.

• METHODS: Retrospective analysis of consecutive cases from clinical practice. Two hundred randomly selected eyes from 200 patients were evaluated before and after LASIK surgery. For each patient, we established the pre-LASIK and post-LASIK spectacle refraction, the pre-LASIK (Kpre) and post-LASIK K readings (Kpost). We then calculated for each case the pre- and post-LASIK refraction at the corneal plane and the amount of correction obtained by the refractive surgery (CRc). The cases were divided into two groups. Group I was used to derive the two formulas. The K values were calculated using the history-derived method (Kc.hd) in which Kc.hd = Kpre – CRc. Kc.hd was compared with Kpost. The average difference was 0.23 diopters for every diopter of myopia corrected. This value was used to calculate the corneal power using the refraction-derived method (Kc.rd) where Kc.rd = Kpost −0.23CRc. A regression equation was used to develop a clinically derived method (Kc.cd) where Kc.cd = 1.14Kpost −6.8. The values obtained with the two methods were compared with the Kc.hd values in group II to validate the results.

• RESULTS: Both Kc.rd and Kc.cd values correlated highly with Kc.hd when plotted on a scattergram ($P < .001$), and there was no statistically significant difference between the mean keratometric values ($P > .5$).

• CONCLUSIONS: The corneal power measurements for intraocular lens power calculations after LASIK need to be corrected to avoid hypermetropia after cataract surgery by either the history-derived method, the refraction-derived method, or the clinically derived method. (Am J Ophthalmol 2003;136:426–432. © 2003 by Elsevier Inc. All rights reserved.)

LASER IN SITU KERATOMILEUSIS (LASIK) IS GAINING IN popularity as the method of choice for the correction of near-sightedness in young adults. More patients in their 40s and 50s are now undergoing refractive corneal surgery in their quest to achieve emmetropia. A number of these patients will develop cataracts, and they will probably expect excellent uncorrected postoperative visual acuity, just as after their refractive surgery. Early experience with eyes that had undergone refractive surgery has shown that the refractive predictability after cataract surgery is relatively poor, however.[1–4] With standard intraocular lens (IOL) power calculations using the post-LASIK K readings (Kpost), the power of the implant used during cataract surgery is usually underestimated, resulting in a postoperative hypermetropic surprise. Different investigators have shown that after refractive surgery, the true value of the corneal power is actually lower than the K readings measured by keratometry or by videokeratography.[1–5] The most accurate way to obtain the correct keratometric values is the history-derived method (Kc.hd) in which the myopic correction achieved at the corneal plane is algebraically added to the prerefractive corneal power.[6–12] This method, also refered to as the Clinical History Method, requires knowledge of the prerefractive corneal power and the amount of myopic correction obtained with the refractive surgery.

The purpose of this study is twofold. First, we describe two methods that can be used to calculate the correct post-LASIK K values when the history-derived method can not be used. These methods were derived from the

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TABLE 1. Information Obtained on Each Operated Eye (in Diopters)

Rs.pre	Pre-LASIK spectacle correction
Rc.pre	Pre-LASIK refraction measured at the corneal plane
Rs.post	Post-LASIK spectacle correction
Rc.post	Post-LASIK refraction measured at the corneal plane
CRc	Amount of myopia corrected at the corneal plane
Kpre	Pre-LASIK K readings
Kpost	Post-LASIK K readings

LASIK = Laser in situ keratomileusis.

review of 100 consecutive LASIK cases. A corrected keratometric value (Kc.rd) can be obtained by using the refraction-derived method; this method is useful when the pre-LASIK K readings are not available, but the amount of refractive correction is known. The other method to obtain a corrected keratometric value (Kc.cd) is based on clinical findings; this clinically derived method uses a regression equation to modify the measured post-LASIK K readings and requires neither the pre-LASIK K readings nor the amount of myopic correction achieved by the refractive surgery. It can be used when these refractive parameters are not available.

The second purpose of this study is to calculate Kc.rd and Kc.cd in a second group of 100 consecutive LASIK cases and to compare the results with the keratometric values obtained by the history-derived method (Kc.hd).

METHODS

WE RETROSPECTIVELY REVIEWED THE PREOPERATIVE DATA and the 3-month postoperative results of 200 myopic patients who have undergone LASIK surgery in one clinical practice. At every visit, a complete eye examination was performed including a manifest refraction. The Sim-K values obtained from a videokeratograph were used for pre- and post-LASIK corneal power measurements.

For the purpose of this study, we randomly selected one operated eye from each patient using an eye selection randomization list. Table 1 shows the information obtained from each selected eye: the pre-LASIK (Rs.pre) and the post-LASIK (Rs.post) spectacle correction and the pre-LASIK (Kpre) and the post-LASIK K readings (Kpost). Spherical equivalent values and average K values were used in presence of astigmatism. In each case, the pre-LASIK (Rc.pre) and post-LASIK (Rc.post) refractive errors were calculated at the corneal plane using the formula

$$Rc = Rs ./. (1 - 0.012Rs).$$

This formula assumes a vertex distance of 12 mm. The amount of myopia corrected at the corneal plane (CRc) was also measured for each case where

$$CRc = Rc.post - Rc.pre.$$

The cases were divided into two groups of 100 eyes each. Group I was used to derive the equations needed to calculate Kc.rd and Kc.cd.

The corneal power was calculated in each operated eye using the history-derived method (Kc.hd) where

$$Kc.hd = Kpre - CRc.$$

It was then compared with the post-Lasik K readings (Kpost) and the difference between Kc.hd and Kpost / diopter (D) of myopic correction was calculated in each case. This difference averaged 0.23 ± 0.11 D. The 95% confidence interval around the mean was (0.22, 0.24). This difference of 0.23 D / D of myopic correction at the corneal level was used to establish the formula used to calculate the keratometric value by the refraction-derived method, where

$$Kc.rd = Kpost - (0.23 \times CRc).$$

To establish the second formula, the measured values of Kpost and the calculated ones with Kc.hd were plotted on a scattergram (Figure 1). The best-fit regression equation was Y = 1.14 x −6.8, and the correlation coefficient was 0.9471. Using this equation and based only on the post-LASIK keratometric readings (Kpost), the corrected keratometric value can then be calculated by the clinically derived method (Kc.cd), where

$$Kc.cd = 1.14Kpost - 6.8.$$

The second group of 100 eyes (Group II) was then evaluated to validate the derived formulas. In each case, we calculated the Kc.rd, and Kc.cd values and compared the results to the Kc.hd values. First, the Kc.rd and Kc.hd values from each eye were plotted on a scattergram. Then the same comparison was performed for the Kc.cd and Kc.hd values. We used the Pearson product-moment correlation coefficient to evaluate each scattergram correlation statistically. We also calculated the mean keratometric value (± standard deviation) obtained with each formula. Paired *t* tests were performed to establish whether there was a statistically significant difference between the mean keratometric values. A *P* value of less than .05 is considered to be significant.

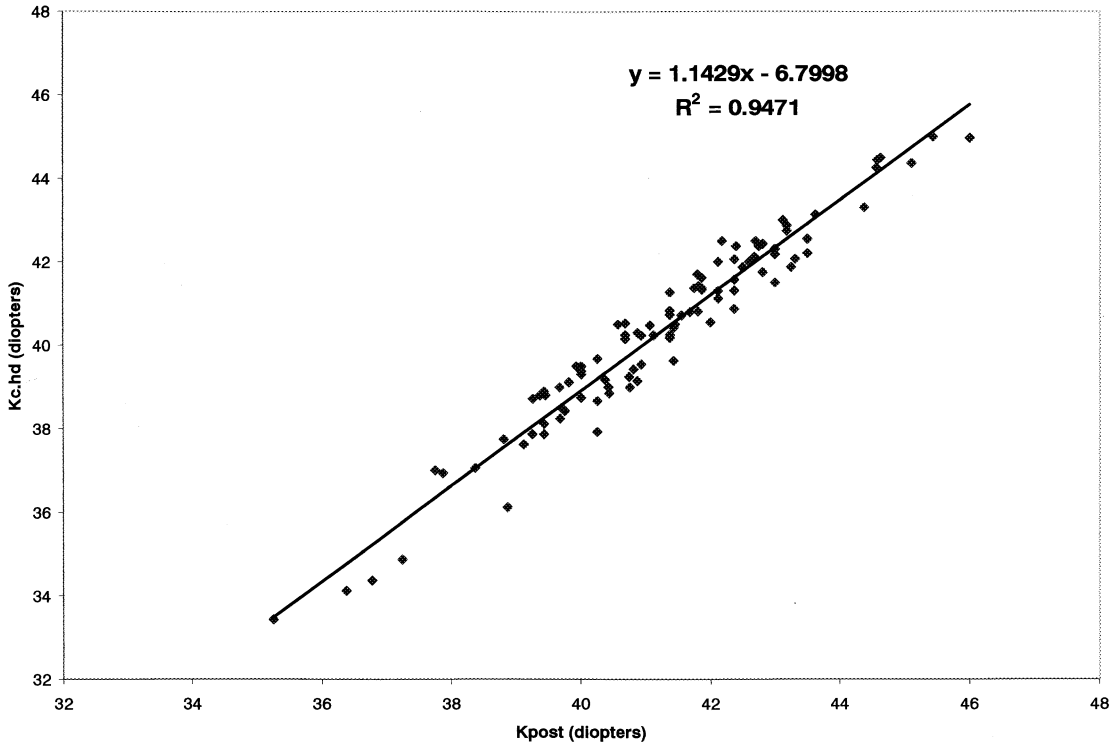

FIGURE 1. Scattergram of the postoperative keratometric readings (Kpost) vs the calculated values using the history-derived method (Kc.hd) in Group I.

TABLE 2. Pre- and Post-LASIK Data

Measured Values	Group I	Group II
Rs.pre	−4.50 ± 2.25 (−1.50 to −12.50)	−4.44 ± 2.12 (−1.75 to −11.00)
Rs.post	−0.15 ± 0.10 (−1.37 to +1.25)	−0.10 ± 0.09 (−1.00 to +1.12)
CRc	−4.15 ± 2.06 (−1.47 to −9.72)	−4.08 ± 1.77 (−1.62 to −9.50)
Kpre	44.15 ± 1.47 (41.12 to 47.62)	44.04 ± 1.48 (41.12 to 47.95)
Kpost	41.25 ± 1.92 (36.37 to 45.43)	41.17 ± 1.84 (36.81 to 46.60)

All measured values are in diopters. Rs.pre = pre-LASIK spectacle correction; Rs.post = post-LASIK spectacle correction; CRc = amount of myopia corrected at the corneal plane; Kpre = pre-LASIK corneal power; Kpost = post-LASIK corneal power. Each group consisted of 100 cases. Group I was used to establish the formulas to calculate Kc.rd and Kc.cd, and Group II was used to validate the results. The results show the average, standard deviation, and the range of these values.

RESULTS

OF THE 200 PATIENTS, 90 (45%) WERE MEN AND 110 (55%) were women. Their ages ranged from 21 to 56 years with an average of 34 years ± 8.2 years. Table 2 shows the average values, standard deviation, and the range of the pre- and post-LASIK data from the two groups used in the study. Each group had 50 right eyes and 50 left eyes.

Figure 2 compares the Kc.rd values with the ones obtained by the history-derived method (Kc.hd) in Group II. The correlation coefficient is 0.97 ($P < .001$). The average value of Kc.rd is 40.23 ± 2.11 D, whereas the average value of Kc.hd is 40.23 ± 2.17 D. The difference between the two mean keratometric values is 0.001 ± 0.50 D and is not statistically significant ($P > .5$). The 95% confidence interval around the mean difference is (−0.10, +0.10).

Figure 3 compares Kc.cd to those obtained by the Kc.hd, also in Group II. The correlation coefficient is 0.96 ($P < .001$). The average value of Kc.cd is 40.21 ± 2.10 D, whereas the average value of Kc.hd is 40.23 ± 2.17 D. The difference between the two mean keratometric values is 0.02 ± 0.58 D and is not statistically significant ($P > .5$). The 95% confidence interval around the mean difference is (−0.14, +0.10).

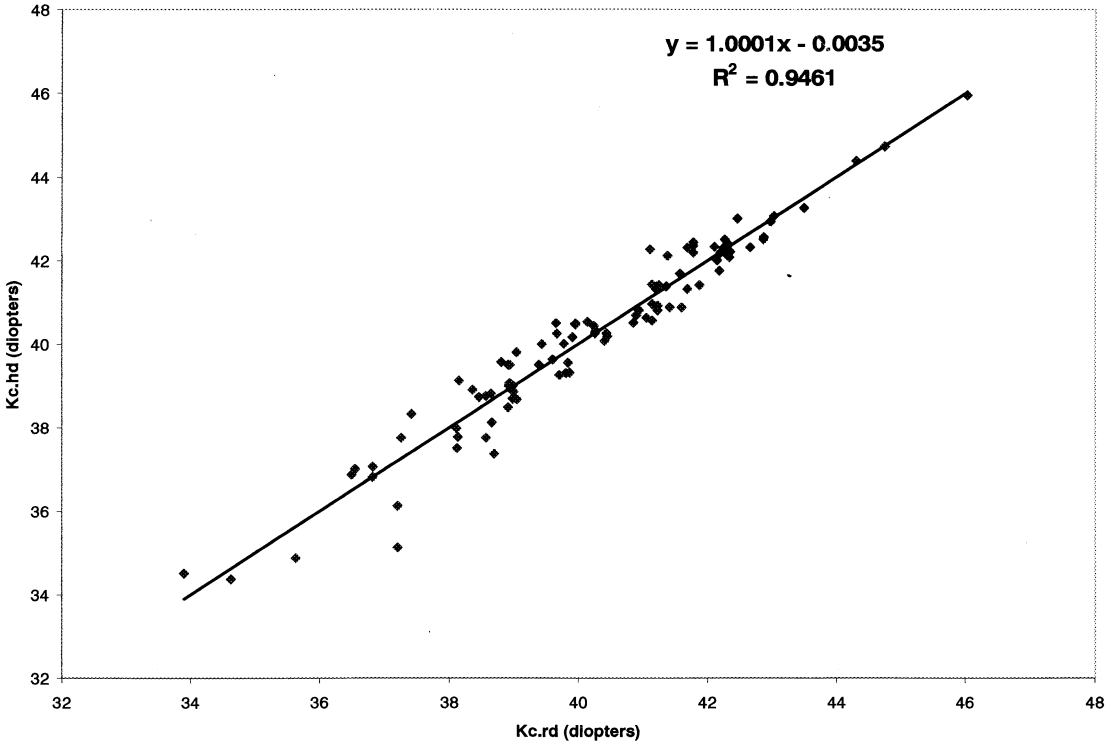

FIGURE 2. Scattergram of the calculated keratometric values using the refraction-derived method (Kc.rd) vs the ones obtained by the history-derived method (Kc.hd) in Group II.

DISCUSSION

THE POWER OF THE CORNEA IS CONVENTIONALLY MEASURED by keratometry. Original keratometers (Javal) measured the total corneal power. That method incorrectly assumed that the back and front corneal radii were equal and therefore used a tear film index of 1.336. Later, to "standardize" the results, an arbitrary index of refraction of 1.3375 was used so that a radius of 7.5 mm would yield 45.0 D.[13] The keratometer measures the anterior radius of corneal curvature, expressed in millimeters, which is translated into diopters by considering the entire corneal power to be at the anterior corneal surface. The relationship between the keratometric readings (K in diopters) and the value of the anterior corneal radius (r in millimeters) is

$$K = 1{,}000\ (1.3375 - 1) \div r.$$

The refractive index of the cornea was measured to be 1.376 by Gullstrand[14] and 1.3771 by Le Grand,[15] who used a sodium light (0.59 μ) for a more accurate measurement. The relationship between the real value of the power of the cornea's anterior surface (D in diopters) and the keratometric readings (K in diopters)[16] is:

$$D = 1.1173 \times K$$

The change in the ratio of the front to the back curvature after LASIK makes the assumed index of refraction incorrect. Because the corneal power is measured at the anterior corneal surface, each diopter of myopic correction should decrease the measurement at the corneal apex by a factor of 1.1173.

In our study, the K readings need to be decreased by a factor of 0.23 D for each diopter of myopic correction obtained by the refractive surgery. Our results confirm the findings of Hamed and associates,[12] which showed a total error of 24%; half of this error (12%) is due to changes in the net index of refraction after LASIK and the additional 11% to 12% error is due to sampling in the periphery of an aspherical corneal surface. The variation in the measurements is because the corneal location of keratometry readings depends on the steepness of the cornea and is not fixed for all eyes, and the readings obtained by corneal topography depend on the number of rings evaluated.

LASIK surgery decreases the corneal thickness. Theoretically, such a decrease has a negligible effect on the corneal power.[12] Also, the posterior corneal surface is presumed to be unaltered with LASIK surgery and its refractive power does not affect the changes noted after refractive surgery. In all calculations, the posterior corneal surface is considered to have a fixed power of –5.90 D. In a study enrolling 263 normal participants, Seitz and Lan-

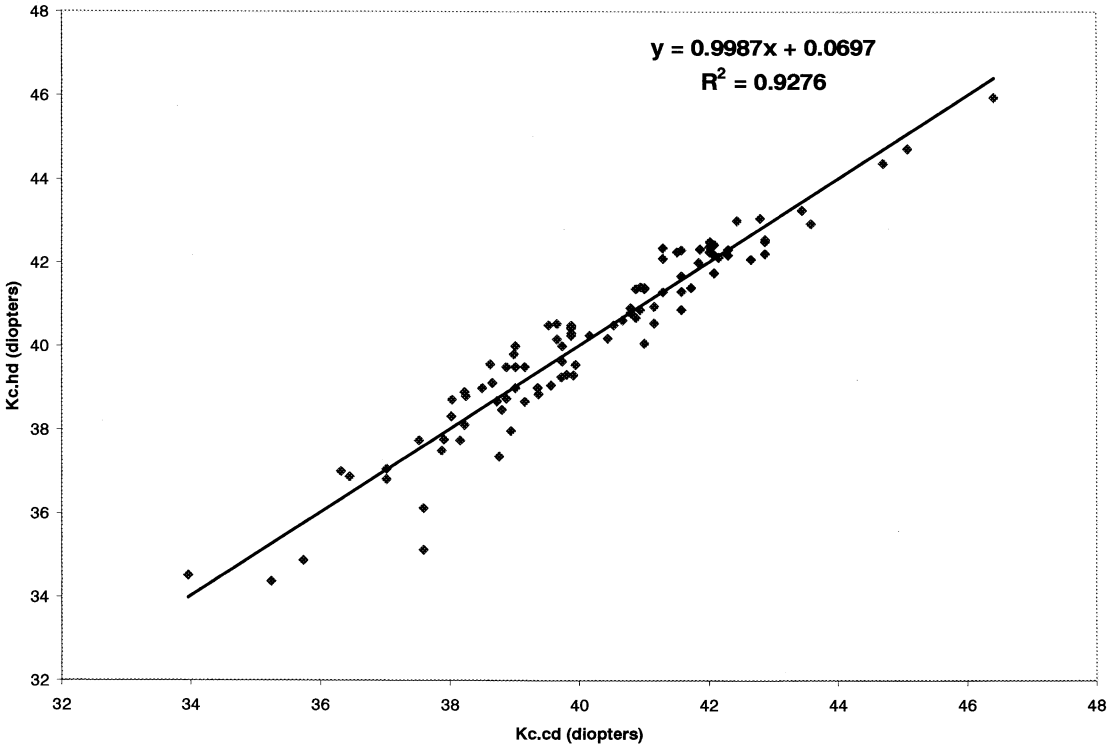

FIGURE 3. Scattergram of the calculated keratometric readings using the clinically derived method (Kc.cd) vs the ones obtained by the history-derived method (Kc.hd) in Group II.

genbucher[7] found a wide interindividual variability in posterior surface keratometric diopters ranging from –2.10 D to –8.50 D. Therefore, adding only the mean value of the posterior surface keratometric diopters to the anterior surface keratometric diopters may cause a considerable error in a given patient. Further studies and newer technology are needed to accurately measure not only the anterior corneal radius but also the posterior one to obtain an exact measurement of the total corneal power.[12]

The contact lens overrefraction method[17] remeasures the corneal power instead of recalculating its value. The patient's refraction is first determined. A Plano hard contact lens of a known base curve is then placed on the eye, and an overrefraction is performed. If the refraction remains the same, the corneal curvature is equal to the base curve of the contact lens. If not, the difference between the over refraction and the original refraction is algebraically added to the base curve of the contact lens; a more myopic change decreases the base curve value, whereas a more hyperopic change increases this value. The limitations of this method are threefold: the availability of Plano hard contact lens in a clinical setting, the difficulty in obtaining an accurate refraction in presence of a cataract, and more important, the difficulty in differentiating a residual myopia from one that has been induced by the cataract. The usefulness of this method in clinical practice is limited, and it was not used in our study.

An accurate way to calculate the true corneal power after LASIK surgery is the history-derived method, also known as the Clinical History Method[6]; the corrected corneal power (Kc.hd) is obtained by algebraically adding the myopic correction at the corneal plane to the preoperative corneal power. This method requires access to the refractive surgery data (pre-LASIK K readings and amount of myopia corrected). Care should be taken not to include in the calculations any myopic shift induced by the cataract. In our study, we used this history-derived method as a benchmark for comparison.

More recently, a refraction-derived method to correct the corneal power after refractive surgery has been advocated.[9–12] Our study confirmed the validity of this method in which the measured post-LASIK keratometry readings are reduced by 0.23 D for each diopter of myopia corrected by the refractive surgery. This method is most useful when the pre-LASIK K readings are not available, but the amount of myopia corrected can be retrieved either from the patient's old glasses or the optometrist's prescriptions.

We describe a new clinically derived method based on a regression equation between Kc.hd and Kpost. The drawback of this formula is that the correction does not relate to the amount of treatment obtained by LASIK; in other words, a −10 D and a −1 D treatment with the same measured postoperative K readings would have the same adjustment. Several studies[9–12] have clearly shown that

the amount of error is directly related to the amount of treatment. This study attempts to derive a mathematical formula to adjust the K readings after LASIK and to more accurately determine IOL power in these patients when neither the pre-LASIK K readings nor the amount of myopia corrected are known. Many patients will not know or be able to obtain preoperative data when the cataract surgery is planned, which could be many years after LASIK. The formula uses only data available at the time of cataract surgery, mainly the post-LASIK K readings. Further evaluation of this method in a prospective study will be needed to establish its validity.

When it is entered into a standard IOL power formula, the post-LASIK K readings are not only used as a measure of the corneal power but also to calculate the effective lens position (ELP) which is the estimated postoperative distance between the anterior corneal surface and of the principal plane of a thin IOL. This measurement is also referred to as the pseudophakic anterior chamber depth. Modern IOL power calculation formulas[18–22] use different methods to calculate the effective lens position; however, they all use the keratometric values in their calculations. In normal cases, a flatter corneal measurement signifies a shallower anterior chamber depth. The IOL power formulas will then calculate a smaller effective lens position and a less powerful IOL to achieve emmetropia. After LASIK surgery, the anterior corneal surface is flattened but the effective lens position is unaltered. The pre-LASIK K values should be entered into the formula to calculate the precise effective lens position (Jaime Arramberi, MD, personal communication). An error in the ELP measurement will occur if the post-LASIK K values are used instead of the pre-LASIK K values. A 1 mm error affects the final refraction by approximately 1.5 D. Furthermore, its effect is cumulative to the error produced by the corneal power's overestimation, yielding the high hyperopic cases reported in the literature.[1–4] A comparison of these formulas shows that, after refractive surgery, the Hoffer Q formula yields a higher IOL power for emmetropia than the other formulas, thus decreasing the refractive error after cataract surgery.[11] The corneal power measurements still need to be corrected by the history-derived method, the refraction-derived method, or the clinically derived method, however, to obtain the most accurate results.

In our study, we compared the new clinically derived method and the refraction-derived method to calculate the correct corneal power to the history-derived method, using the latter as a benchmark. A-scan measurements of the axial length were not performed in our cases. A better benchmark for comparison would be in determining the IOL power before LASIK surgery using standard calculation techniques with K readings and axial length measurements. Further prospective studies are needed to confirm our results and establish the validity of these methods used to correct the corneal power measurements for IOL power calculations after LASIK.

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